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Research Article

MAINTENANCE MANAGEMENT AND RELIABILITY IN CASE OF PIECES REPLACEMENT OR MENDING WITH A FUZZY LOGIC APPROACH

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ABSTRACT
Almost all organizations use machinery and equipment which are worn out in course of time and which will need to be repaired or replaced. Replacing pieces may reduce efficiency while increasing the operational and maintenance costs, or it may lead to the complete failure of the pieces. In the present study, we want to find the most proper time for replacing the pieces collectively. In the recent years, the fuzzy logic approach has found extensive functions in the issues related to the net. The reason for the interest in this logic can be explored in the lack of trust in the nature of net issues and also the elimination of effective variables in the problems due to the probability assumptions and laws such as sample volume, sampling possibility and the necessity of existing a sample. In this research, besides offering the basics, the reasons of using the fuzzy approach in the maintenance issue are mentioned, and then an applied model is presented.

Keywords: *Maintenance, Reliability, Fuzzy Logic*

INTRODUCTION
Maintenance management is a branch of industrial management and industrial engineering which by controlling the productive machinery and equipment in terms of scheduling plan of pieces replacement and by means of mathematical models of statistical analyses reduces the maintenance costs and perseveres the pieces at the best level. Maintenance management is an art, because before the outbreak of a problem and also at the time of happening such incident, there is the opportunity for selecting different approaches and activities, and here we have the maintenance managers who play a more effective role than the other parameters, even more than the nature of the emerged problem.
Maintenance and special mending management, depending on the organization, can play a great role in the reduction of the cost price of a final product. However, these effects are not bound to the costs, and they can be felt in the speed of product presentation in the total supply chain, the quality of the product, the reliability, and the agility of the organization (Jafarnezhad and Ismaeelian, 2012).

Maintenance Concepts
The experiences of the organizations show that by using proper methods of maintenance in organizations, the costs can be dramatically reduced. The maintenance managers have managed to succeed in their careers, by using a proper combination of maintenance methods and by controlling the organizational performance more effectively (Jafarnezhad and Ismaeelian, 2012). Types of Maintenance are including:
a. Corrective Maintenance
b. Preventive Maintenance
c. Emergency Maintenance

Maintenance involves a series of activities in order to conserve or restore a condition of a particle or the total system which leads to the following results (Jafarnezhad and Ismaeelian, 2012):
1. Increase of efficiency
2. Increase of work and product security
3. Increase of lifetime of the machines and equipment and preventing from their depreciation
4. Reduction of the devices and machinery stoppage hours
5. Reduction of utilization costs

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6. Reduction of spare pieces consumption
7. Prediction of the amount and the time of pieces consumption
8. Reconstruction and reusing of the pieces
9. Supplying the proper work or product quality

The increase of the investments on the industrial machinery and automation and also the increase of financial and economic values of these machines persuaded the industries managers to think of some strategies in order to optimize the useful life and prolonging the economic lifetime of the production equipment. Since 1930 onward, we can divide the development course of the maintenance field, into three main periods (Jafarnezhad and Ismaeelian, 2012), as shown in the following table:

Table 1: The Maintenance Management Development And Its Achievements In Each Period

First Period	Second Period	Third Period
• Preventive Emergency Maintenances (EM) • Breakdown Maintenance (BM)	• Increase of the readiness • Increasing the equipment lifetime • Reduction of the costs	• Technology development • Increase of readiness • Reduction of the incidents • Increase of the product quality • Protecting the environment • Increase of the equipment lifetime • Reduction of the costs

Fuzzy Logic

The traditional and classical methods of modeling, logic, inference and calculations have a value dichotomy of yes or no, and black or white. However, it is so difficult to draw sharp and definite lines among the phenomena and the work relations, in the outside world and in the reality, and in most cases, explicit judgments are impossible. In the fuzzy theory, unlike the traditional methods, the series limits are not definite and determined and the bases of judgment are terms like low and high. In other words, in fuzzy systems, the type of modeling and logic is approximate and in fuzzy series, the sequence of each element is according to its membership degree in the series. This idea is the basis of the fuzzy logic and series proposed by Professor Lotfi A. Zadeh , not more than four decades ago , though it faced different opposite views at first. Nevertheless, nowadays in most scientific and academic institutions, the fuzzy logic is approved and studied by the scholars and experts (Fazel-Zarandi, 2000).

Fuzzy Mathematics

Most applications of fuzzy logic in different sectors refer to the fuzzy numbers and the fuzzy membership functions in the mathematical relations ruling them. In fact, at the moment, the fuzzy logic is developing in two directions, firstly the internal principles of the fuzzy logic that are related to the mathematics of this logic which consolidate this logic and leads to the evolution of the general format of this logic which a rising development course .The second direction is to solve the applied problems in various scientific realms. In the second direction, which is to use the fuzzy concept facing the real world problems, there have been many attempts in most scientific fields (Zimmerman, 1990).

Triangular Fuzzy Numbers

The triangular fuzzy number of is the one as $A = (a_1, a_m, a_2)$ wherea_1 and $a_2$are the left and right limits and the point $(a_m, 1)$is the peak.

$$f(x) = \begin{cases} (x - a_1)/(a_m - a_1) & a_1 \leq x \leq a_m \\ (x - a_2)/(a_m - a_2) & a_m \leq x \leq a_2 \\ 0 & \text{other wise} \end{cases}$$

While investigating an uncertain number, if we are able to determine the least and the most possible amounts, in fact we have found the limits of a fuzzy number as $A = [a_1, a_2]$. In the next step, if we are able to determine the amount of a_m in the interval of $[a_1, a_2]$as the most justified possible number for displaying the uncertain amount, then the peak would be$(a_m, 1)$. This point can be the most frequency and one should get help from the experts to find it. Now, with (a_m, a_2, a_1) , a triangular fuzzy number can be formed, and its membership function can be written according to the aforementioned phrase. Hence, this is the reason why the triangular fuzzy number is shown as follows:

$A = (a_1, a_m, a_2)$

Reliability

Reliability is a very important concept that by the complication of the automation system is required more and more by the production and service systems. Reliability can be optimally increased despite the existence of very complicated systems, which is itself a quality assessment scale (Seyyed, 1997). It is obvious that in different processes, we can reach a high reliability with a proper planning. The effective maintenance of the modern complicated systems requires huge costs, and meanwhile what can be admitted as the guarantee for such investments is the existence of reliability.

Classical Problems with Reliability

1- The optimal time interval for replacing the pieces which are liable to breakdown
2- The optimal replacement policy for two machines as reserves, with the target functions of the least cost or the stoppage time or maximizing the profit
3- Collective replacement like replacing the street lights in a city
4- Planning for inspecting the machinery and equipment (Seyyed, 1997)

Serial and Parallel Systems Reliability in Fuzzy State

The reliability of the serial systems in fuzzy state is calculated using the following relation.

$$R_s = \left(\prod_{i=1}^{n}(m_i - \alpha_i), \prod_{i=1}^{n} m_i, \prod_{i=1}^{n}(m_i + \beta_i)\right)$$

Where α and β are in order, the left and right limits.

The reliability of the whole system is calculated from the above relation and the reliability of the parallel system is calculated from the relation below (Singer, 1990):

$$R_s = \left(1 - \prod[1 - (m_i - \alpha_i)], 1 - \prod(1 - m_i), 1 - \prod[1 - (m_i + \beta_i)]\right)$$

The Collective Replacement Model in Fuzzy Environment

Maintenance of street lights is of the classical issues of the preventive and modifying replacement area. The problem is generally in this way that the regional lighting company responsible for the street lights, has *n* lamp post in its area, which has one lamp. In this kind of problems, collective replacement is more successful than the single replacement methods at the time of failure. The reason can be the high cost of getting an electrician and the related equipment for replacing a single lamp and also the discount given when the lamps are wholesaled.

However, considering the collective replacement costs, the best decision is to establish a balance between the collective replacement costs and the reliability of the system which is having enough light. This goal can be gained by the help of the optimal time interval for the collective replacement. The higher the time interval is, the more the costs are saved, while the reliability is descending (Cai-Yuan and Chuan-Yuan, 1990).

In order to form a fuzzy series of the system, we assume that by failing each lamp, we get a little further from the proper state in the system, and by having any more lighted lamp , the system's status is better. If we demonstrate this problem as a linear fuzzy membership function, while having the total number of lamps as N, then the number of the lighted lamps divided by the total number can be an indicator of the system status. At the moment zero, all the lamps reach the desired limit of 1, and at the worst situation, that is the failure of all lamps, the lamps will reach zero. The reliability here is calculated from the relation below:

$$R(t) = \sum_{j=1}^{N}(j/k) * C_N^j * [1 - F(t)]^j * [F(t)]^{N-j}$$

Where T (system transformation variable) is the unknown object of the problem and F(t) is the lamp lifetime distribution function, and C_N^j is calculated from the relation:

$$C_N^j = N!/[j! - (N - j)!]$$

Considering the fact that the final goal of the problem is to calculate the optimal time of periodical replacement shown as T, so we should make a target function like Q(T) which can give us the optimal T, while going for the goals such as minimizing the costs and maximizing the reliability. Since the reliability and the costs do not have the same scales, we use two weight coefficients as w_1 and w_2 for combining them. Naturally if the model does not have any limitations, the result would be infinite T. In order to prevent from this result, we consider a low limit for R (T), which is a given number.

$$\mathrm{MiNQ(t)} = w_1 * c_1 - w_2 \int_0^T R(t)\, d_t$$

ST: $R(t) \geq p$

Maintenance Fuzzy Model

In the classical model of maintenance, in case of the pieces that should be replaces, an optimal time interval is calculated, according to the failure probability distribution. However, in fuzzy models, all the variables and parameters are fuzzy variables.

If we assume the planning horizon duration limited, the time plan is divided into periods whose durations are variable. For each time of replacement or mending operation, the current period is over and the next period is started. In each period, the piece condition at the start of the period, its condition at the time of activity, and its condition at the end of the period are all a triangular fuzzy variable. The duration of each period is calculated according to these very parameters.

The type of the maintenance operation in three different states with different membership functions as a triangular fuzzy variable. At the end of each period, a piece is undergone one of the three maintenance operations or is replaced. Replacement is done in one of the two following circumstances: the replacement cost be lower than the maintenance operation cost or the piece lifetime reaches the replacement stage, according to a logic that will be presented. When a period is over, the system status is evaluated at the start of the next period, and the operational status of the system at that period, is also calculated by simulating the fuzzy variable.

Table 2: Problem Variables

Problem Variables	
i: period i	Mci : the maintenance costs of period *i*
Δt_i: period i duration	RC : Replacement Cost
t_i : piece lifetime until period i	SC_L : the fuzzy variable of the Lth state at the start of the period
γ_i : lifetime factor of period i	$OC_{K:}$ the fuzzy variable of the operational Kth state of the period
tmj : the maximum piece j lifetime before replacement	$EC_{Q:}$ the fuzzy variable of the Qth state at the end of the period
	ME_n: the fuzzy variable of the nth type of the maintenance operation
	Wp: the fuzzy variable of the pth significance degree
	δ_n : the Euclidean distance for nth type of the maintenance operation

Model Assumptions

1. The ignorable maintenance time
2. Start condition, operational condition, and the end condition of the fuzzy variables are at the [0, 10] distance.

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3. γ_i factors in each period i , depend upon the start condition , operational condition and the functional lifetime of the device in that period.
4. The cost variable in each period depends on the maintenance operation type, piece lifetime, and the end condition of the period, though with different weight coefficients.

Variables

These variables are the indicators of the start, operation and end conditions. The purpose is to eliminate the completely sound or completely failed conditions. These variables in five ranges, determine various amounts between completely sound and completely failed conditions.

OC which stands for the operational condition in each period is the most important fact which plays a great role in determining the type of the maintenance operation. This variable is calculated by means of fuzzy variable simulation in each period (Chanas and Nowakowski, 1988).

EC or the end condition of each period is calculated according to the start condition, operational condition of each period and the period duration.

Table 3: The variables related to the period conditions and their membership functions

The start condition of the period

1	SC_1	Excellent	(0,0,2)
2	SC_2	Good	(1,2,4)
3	SC_3	Medium	(3,4,6)
4	SC_4	Bad	(5,6,8)
5	SC_5	Very Bad	(7,8,10)

The operational condition of the period

1	OC_1	Excellent	(0,1 ,2)
2	OC_2	Normal	(2,3 ,5)
3	OC_3	Bad	(5,6 ,8)
4	OC_4	Deleterious	(8,9 ,10)

The end condition of the period

1	EC_1	Good	(0,2 ,3)
2	EC_2	Medium	(2,4 ,5)
3	EC_3	Bad	(4,6 ,7)
4	EC_4	Very Bad	(6,8 ,9)
5	EC_5	Critical	(8,10 ,10)

In order to apply this different weight coefficient to the fuzzy variables, we need a series of significance degree fuzzy variables which is shown by W1, W2, and W3. These variables are as follows:

Table 4: The fuzzy series for different significance degrees

1	W_1	Very Important	(0.8, .09, 1.0)
2	W_2	Important	(0.5, 0.6 , 0.7)
3	W_3	Less Important	(0.0, 0.2 , 0.4)

Since maintenance has different levels and also needs a variety of tools and environments, three different conditions have been considered for this variable that is partial, average and whole. This variable which is shown by ME, depends on the end condition, operational condition and the piece lifetime.

Table 5: Fuzzy series of three different maintenance levels

1	ME_1	Little	(1, 2,3)
2	ME_2	Medium	(4, 5,6)
3	ME_3	Main	(7, 8,9)

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Calculations and Formulas

Step 1: we consider the Weibull distribution as failure statistical distribution with parameters β and θ. Also, the duration of the first period with the least permitted reliability is calculated from the relation below.

$$t_1 = \left[(\ln R)\Theta^{\beta}\right]^{1/\beta}$$

R and t are both fuzzy variables.

Step 2: for each time, an amount of the lifetime reduces which is called the age factor, shown by γ_i.

$$\Delta t_2 = t_1 - \left(\frac{t_1}{\gamma_2}\right)$$

$$t_2 = t_1 + \Delta t_2$$

$$\Delta t_i = t_1 - \left(\frac{t_1}{\gamma_i}\right)$$

$$t_i = t_{i-1} + \Delta t_i$$

Step 3: In order to calculate the period durations, we should just calculate the age factor. This factor depends on the primary lifetime of the system at the beginning, start condition and the current operational condition.

$$S(i) = (OC_k * w_1 + t'_{i-1} * w_2 + SC_i * w_3)/(w_1 + w_2 + w_3)$$

$$\gamma_i = 10/Si$$

In order to apply $T_i, \Delta t_i$ in the calculations, their balanced amounts are needed at [0,10] , so that the scale be kept, in relation to the other variables.

$$\Delta t'_i = \Delta t_i * (10/\Delta t_i)$$

$$t'_i = t_i * (10/T)$$

Where T is the maximum piece lifetime.

Step 4: Maintenance Factor (MF)

Calculating the MF which is a triangular fuzzy variable.

$$MF_i = (EC_q * w_1 + OC_k * W_2 + t'_i * w_3)/(w_1 + w_2 + w_3)$$

MF_i is calculated and the best maintenance type is selected by using the Euclidean distance.

Step 5: maintenance levels calculation

The Euclidean distance of Cut *a*

$$\delta(MF_i, ME_i) = \left[\sum_{\alpha=0}^{1} (MF_{imin} - ME_{nmin})^2 + (MF_{imax} - MF_{nmax})^2\right]^{0.5}$$

The amount of δ is calculated according to n=1, 2, 3 and the n related to the least amount is selected as the maintenance operation type.

Step 6: calculating the system's degrading factor

The degrading factor (DF_I) is calculated and through that, the system condition at the end of the period is calculated.

Table 6: Determining the end condition of the period (k), per the star condition of (1) and the degrading factor (DF)

K	0<DF<0.2	0.2≤DF<0.4	0.4≤DF <0.6	0.6≤DF<0.7	0.7≤DF <1.0
1	1	2	3	4	5
2	2	3	4	5	5
3	3	4	5	5	5
4	4	5	5	5	5
5	5	5	5	5	5

Step 7: calculating the improvement factor

$$S_{i+1} = \pi r^2 = (ME_n * w_1 + (10 - t'_{i-1}) * w_2 + EC_q * w_3)/(w_1 + w_2 + w_3)$$
$$IF_{i+1} = S_{i+1}/10$$

The improvement factor (IF_{i+1}) is calculated and through that the system condition at the beginning of the next period is computed.

Table 7: Determining the start condition (1) SC_{i+1}, per the end condition (K) and the improvement factor

i	0<IF<0.4	0.4≤IF<0.6	0.6≤IF <0.7	0.7≤IF<0.8	0.8≤IF <1.0
1	1	1	1	1	1
2	2	1	1	1	1
3	3	2	1	1	1
4	4	3	2	1	1
5	5	4	3	2	1

Step 8: Calculating the Costs

$$Mc_i = (r * AC_1) * [ME_n * w_1 + t'_i * w_2 + EC_q * w_3)]/[(w_1 + w_2 + w_3)]/10$$

R is a constant coefficient which presents the maintenance cost as a fraction of the primary price.
The calculated maintenance cost is compared to the replacement cost , and if the replacement policy is selected , do it and go to step 9.

Step 9: Lifetime Limitation

By the use of Figure 1, the lifetime limitation of the device is investigated and in case of being at the replacement stage, instead of mending and maintenance operation, apply the replacement policy and go to step 9.

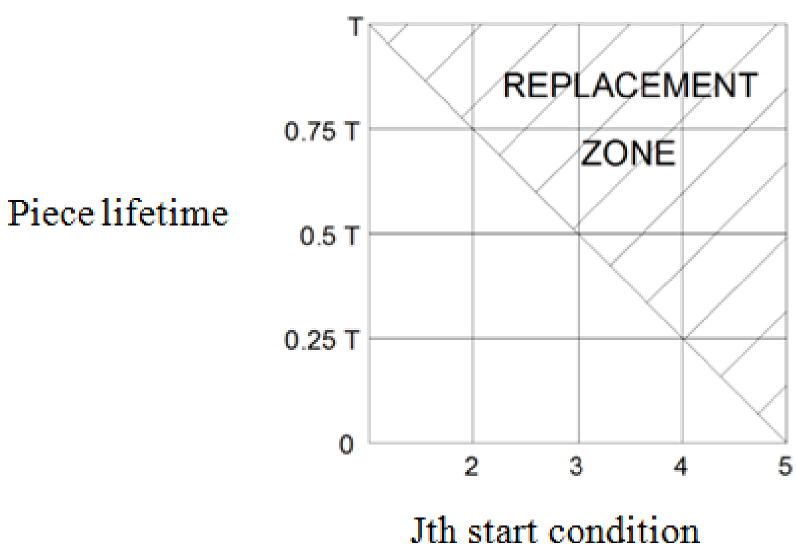

Figure 1: The replacement limitation according to the performance and lifetime

Step 10: the steps 3 to 9 are repeated as far as the total time of the planning horizon is not exceeded.

- Time unit = hour (the table numbers are per weeks- per 40 hours a week)
- Planning horizon = 104 weeks (2 years)
- The start condition for all the pieces-=SC_1 = (0,0,2)
- The rate of pieces costs increase = 0
- r_2= 0.15 (the ratio of the maintenance costs and the piece price)
- Decision Alternatives= Replacement or maintenance at levels 1,2, or 3

Table 8: The primary amounts of the problem

	Piece Name	First Period Duration	Maximum Possible Lifetime	Piece Cost	Maintainability?
1	PU Friction Disk	(3.5,4.0,4.5)	(48,52,56)	1000	Unmaintainable
2	Cots	(7.5,8.0. 9.0)	(96,104,112)	300000	Maintainable
3	Tangentional Belt	(5.0,6.5, 7.0)	(520و 520و 520)	5000	Unmaintainable
4	Guide Ceramic	(1.5,2.0,2.5)	(12,14,16)	1000	Unmaintainable
5	Timing Belt	(3.0,4.0,5.0)	(12,14,16)	15000	Unmaintainable
6	Yarn Guide Assembly	(3.0,4.0,5.0)	(14,16,18)	40000	Unmaintainable
7	Take-Ip Cylinder	(0.5,1.0,1.5)	(10,12,14)	5000	Unmaintainable
8	Platinum Thermo resistance	(3.0,4.0,5.0)	(48,52,56)	2000	Unmaintainable
9	Jet insert	(1.5 ,2.0, 2.05)	(6,8,10)	140000	Maintainable

Choosing the Maintenance Policy against Replacement

The maintenance and replacement policy-making in a system with a limited planning horizon, is possible when the duration times between maintenance and replacement is calculated by the age factor and the age of the device (system) is updated. The maintenance operation type is calculated by the use of the maintenance factor and Euclidean approximation. The improvement factor is used for finding the start condition of the system at the next period and the degrading factor is used for finding the system condition at the end of the period. Comparing the maintenance cost against the replacement cost will be the criterion for deciding on the maintenance or replacement, if in terms of calculations, the maintenance is not possible and the piece must inevitably replace.

CONCLUSION

As a summary of the discussed issues, we can say that in environments where the uncertainty plays vital role and where the sample cases are not accessible for several reasons, the different strategies presented in this research can be very effective, considering this fact that especially in most cases, the fuzzy variables of the events resulting from the theories of the experts in each workplace, are more flexible than the classical probability function.

Also, using the decision tree or the fuzzy variables are highly effective in the analysis of the complicated systems involving elements with different properties. In case of timing issues of the maintenance in industrial environments, the models based on the fuzzy logic, with high flexibility and covering all the available and indefinite variables of the workplace, can be more efficient in presenting the best maintenance strategy, and a very important note here is that by changing the input information, during the program execution, the models will be more updatable and more flexible.

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